AUTOMATIC GENERATION OF HIGH QUALITY DSM BASED ON IRS-P5 CARTOSAT-1 STEREO DATA

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ABSTRACT

IRS-P5 Cartosat-1 high resolution stereo satellite imagery is well suited for the creation of digital surface models (DSM). A system for highly automated and operational DSM and orthoimage generation based on IRS-P5 Cartosat-1 imagery is presented, with an emphasis on automated processing and product quality. The proposed system processes IRS-P5 level-1 stereo scenes using the rational polynomial coefficients (RPC) universal sensor model. The described method uses an RPC correction based on DSM alignment instead of using reference images with a lower lateral accuracy, this results in improved geolocation of the DSMs and orthoimages. Following RPC correction, highly detailed DSMs with 5 m grid spacing are derived using Semiglobal Matching. The proposed method is part of an operational Cartosat-1 processor for the generation of a high resolution DSM.

Evaluation of 18 scenes against independent ground truth measurements indicates a mean lateral error (CE90) of 6.7 meters and a mean vertical accuracy (LE90) of 5.1 meters.

1. INTRODUCTION

In May 2005 India launched its IRS-P5 Cartosat-1 satellite equipped with the PAN-Aft and PAN-Fore instruments which is a dual-optics 2-line along-track stereoscopic pushbroom scanner with a stereo angle of 31° and the very interesting resolution of 2.5 m. Cartosat-1 high resolution stereo satellite imagery is very suitable for the creation of digital surface models (DSMs). In this paper, a system for highly automated DSM generation based on Cartosat-1 stereo scenes is presented. More details about Cartosat-1 are given in [9].

Cartosat-1 stereo scenes are furnished with a rational polynomial functions (RPC) sensor model [2], derived from orbit and attitude information. The RPC have a much lower absolute accuracy than the ground resolution of approximately 2.5 m. Subpixel accurate ground control points (GCPs) have been used in previous studies to estimate bias or the affine RPC correction parameters required for the high quality geolocation of high resolution satellite images [6]. Such highly accurate GCPs are usually derived from a DGPS ground survey or high resolution orthoimages and digital elevation models.

For large scale and continent-wide processing, the establishment of a highly accurate GCP database with the density required for processing the relatively small Cartosat-1 scenes (900 km²) requires significant resources. For near real-time applications such as disaster assessment tasks in remote regions, highly accurate GCP data are often not available.

We propose the use of widely available lower resolution satellite data, such as the Landsat ETM+ and SRTM DSM datasets as a reference for RPC correction. The accuracy of these datasets is low compared to the high resolution Cartosat-1 images. The absolute lateral error of ETM+ Geocover is 50 m (CE90), the absolute lateral error of SRTM is between 7.2 m and 12.6 m (CE90, depending on the continent), with an absolute height error of 4.7 m to 9.8 m [8]. The traditional method of collecting lateral position from a reference image and interpolating the corresponding height from the DEM ignores the higher lateral accuracy of the SRTM dataset. Our method avoids this drawback by using an RPC correction based on DSM alignment, resulting in improved geolocation of the DSMs and orthoimages generated.

Digital surface models are derived from dense stereo matching and forward intersection, with subsequent interpolation into a regular grid. The first part of this paper describes the process used for DSM generation, with specific emphasis being placed on the georeferencing. The second part evaluates the processor using 18 Cartosat-1 stereo pairs for which high quality kinematic GPS transects are available.

2. CARTOSAT-1 STEREO PROCESSOR

The DSM generation process consists of the following main steps, implemented as part of the DLR`s XDibias image processing system.

1. Stereo matching in epipolar geometry
2. Affine RPC correction and alignment to reference DEM

3. Forward intersection and outlier removal
4. DSM interpolation
5. Orthorectification

2.1. Stereo matching

Hierarchical intensity based matching is used for matching the stereo pairs and the reference image. This consists of two major steps, hierarchical matching to derive highly accurate tie points and dense, epipolar based stereo matching.

The initial matching step uses a resolution pyramid [7;5] to accommodate large stereo image distortions resulting from carrier movement and terrain. Large local parallaxes can be handled without knowledge of exterior orientation. The selection of pattern windows is based on the Foerstner interest operator which is applied to one of the stereo partners. For selection of search areas in the other stereo image(s), local affine transformations are estimated based on already available tie points in the neighborhood (normally from a coarser level of the image pyramid). Tie points with an accuracy of one pixel are located using the maximum of the normalized correlation coefficients, computed by sliding the pattern area all over the search area. These approximate tie point coordinates are refined to subpixel accuracy by means of local least squares matching (LSM). The number of points found and their final (subpixel) accuracy achieved depend mainly on image similarity and decrease with increasing stereo angles or time gaps between images. Strict thresholds on correlation coefficient and bidirectional matching differences are used to select reliable and very accurate stereo tie points.

An epipolar stereo pair, with epipoles corresponding to the image columns, is generated by aligning the columns of the Fore image with the Aft image, using very accurate matches from the pyramidal matching step. Dense stereo matching is performed on the epipolar images, using semiglobal matching (SGM) [4]. SGM avoids using matching windows, and is thus able to reconstruct sharp object boundaries. Instead of assuming a locally planar surface, as done by least squares matching, a global energy function is minimized for all disparities (local shifts between the stereo pair). This energy function consists of a pixel-wise matching cost and a regularization term. Both the Mutual Information [4] as well as the Census cost function [10] are used. These cost function adapt to brightness changes in the stereo images and allow matching of images with large viewing angle differences. SGM performs a semi global optimization by aggregating costs from 16 directions, to reconstruct a near optimal disparity image D. The regularization term penalizes small disparity changes with a small penalty p_1, and larger disparity jumps with a constant penalty p_2. The regularization term favors similar or slightly changing disparities between neighboring pixels, and thus stabilizes the matching in image areas with weak contrast, but also allows large disparity jumps when needed.

Several consistency checks and outlier removal steps are applied in order to remove almost all remaining matching outliers [1].

2.2. Georeferencing

Previous studies [6] have shown that the Cartosat-1 RPC ground accuracy is in the order of several hundred meters. Furthermore, forward intersection performance without RPC correction is poor and results in large residuals in image space. The estimation of affine RPC correction parameters requires well distributed GCPs with subpixel accuracy. In many application scenarios, such as continent wide reconstruction or crisis support applications, acquiring the required GCPs is a time consuming task or might even be impossible, if a fast response is required.

Landsat ETM+ Geocover mosaic and SRTM elevation data are readily available global reference datasets. The accuracy of these datasets is low compared to the high resolution Cartosat-1 images. The Landsat ETM+ Geocover mosaic is specified with a lateral error of 50 m. The absolute lateral error of SRTM amounts to 7.2 m - 12.6 m (CE90, depending on the continent), with an absolute height error of 4.7 m to 9.8 m [8].

GCPs are collected by transferring highly accurate tie points from the Cartosat-1 Aft and Fore images to the Landsat reference image and then extracting the corresponding height from SRTM. Preliminary affine RPC corrections for both Aft and Fore images are then estimated using these GCPs.

2.3. RPC correction by DSM alignment

Following the alignment based on ETM+ and SRTM reference data, forward intersection residuals are significantly improved, but the lateral accuracy is still limited by the ETM+ Geocover reference. To take advantage of the higher accuracy of the SRTM dataset, a second RPC correction step is necessary. A 3D point cloud is calculated by forward intersection of a subset of the stereo tie points. The point cloud is aligned to the SRTM DSM, and used as input for the final estimation of the affine RPC correction parameters.

2.4. DSM and orthoimage

The result of the matching and forward intersection is a set of 3D points representing the Earth surface (including e.g. tree tops) acquired from the stereo images. To facilitate further applications, the irregular point cloud is converted to a regularly spaced grid with a spacing of 5 m. If multiple points fall into the same grid cell, their heights are averaged to form a new point. Remaining holes are filled with SRTM data, using the delta surface fill algorithm [3]. Orthoimages with a user defined datum and projection are created by orthorectification of the Aft image with the generated DSM and the affine corrected RPC.

3. EVALUATION

3.1. Evaluation strategy

For an independent examination of the horizontal and vertical accuracy of the digital surface models, kinematic GPS transects were used as a reference dataset at 18 test sites. The software used for accuracy assessment was developed by the GAF AG programming department.

A two step procedure is followed in order to ensure the quality of the reference dataset: the first step involves the automatic detection and elimination of erroneous GPS measurements and the second step results in GPS points that are considered as not reliable, as they provide incorrect heights in comparison to the DSM (e.g. bridges, forest, ...), being deleted.

After eliminating incorrect GPS measurements the vertical accuracy is calculated by comparing the GPS height and DSM height for each pixel. The vertical accuracy (LE90) is subsequently computed for each test site.

As a next step, the horizontal accuracy is calculated by finding the minimum standard deviation of height differences of the track in the north-south and east-west directions and then calculating the CE90 based on the length of the resulting shift vectors (see Fig.1).

These results are checked by visually comparing the track with the orthoimage.

18 test sites from within the Euromap IRS-P5 acquisition footprint and well distributed across Europe, Turkey and North Africa were chosen for the accuracy tests. Various criteria were important for the identification of test sites – e.g. good coverage by the GPS transect, a range of landscapes, such as urban areas, forested areas, agricultural areas,- and dry areas, and also various types of relief (flat, hilly, mountainous).

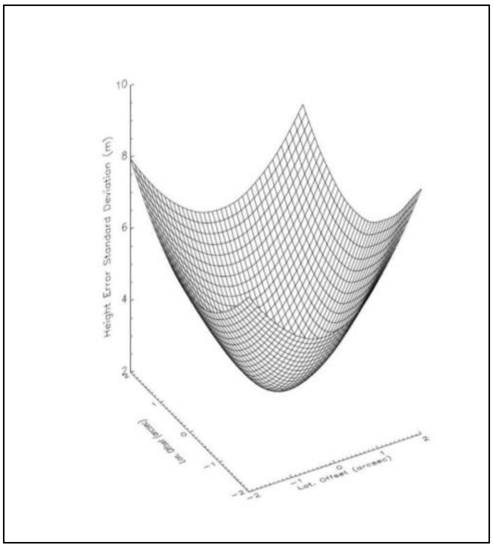

Figure 1: Surface plot of the standard deviation of the height error sampled along a kinematic GPS track over a mountainous SRTM cell [8]

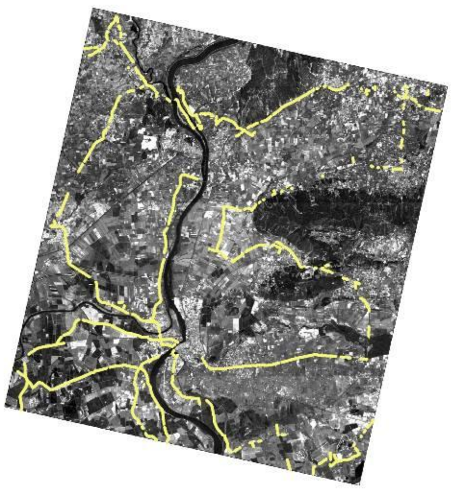

Figure 2: 2.5 m orthoimage from a test site around Arles (France) with the corresponding GPS transects

Additionally, the slope-dependent and area-wide accuracy will be tested for an area in the northern part of Italy covered by approximately 420 stereo pairs (Po plain, 90,000 km²). Such tests are also very important for examining the methods used for image block adjustment. In this case, the better horizontal accuracy of DSMs generated in more textured areas (Alps, Apennines) will be used for compensating (adjusting) the potentially worse horizontal accuracy in very flat and un-textured areas (Po plain).

3.2. Results

The accuracy tests, using 18 single IRS-P5 DSMs scattered across Europe which were processed individually, confirmed a horizontal accuracy (CE90) of 6.7 m and a vertical accuracy (LE90) of 5.1 m.

When comparing the LE90 values of the test sites with the LE90 values of the SRTM tiles and the continent-wide calculated CE90 values of SRTM, the IRS-P5 values are similar or even better.

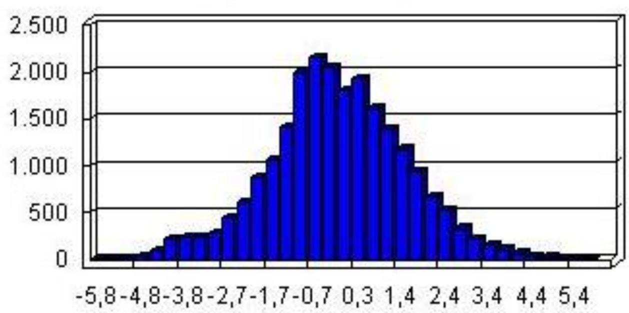

Figure 3: Frequency distribution of height differences between DSM and GPS height values in Arles (France)

Table 1: Vertical and horizontal accuracy at 18 test sites

Test area	Description	LE90 (m)	CE90 (m)
Ankara	Urban, hilly	3.9	4.2
Kastamonu	Urban, hilly	3.4	2.2
Uzunköprü	Agriculture, flat	8.3	4.0
Arles	Wetlands, agriculture, flat	2.6	9.4
Nebelhorn-north	Mountainous	3.9	4.6
Nebelhorn-south	Mountainous	4.1	5.8
Munich	Urban, agriculture, flat	6.3	4.3
Heidelberg	Forest, urban, agriculture, hilly	5.2	5.8
Koblenz	Forest, urban, open cast mining, hilly	7.1	5.6
Relizane	Dry, flat	5.9	6.9
Gospic	Forest, hilly	8.4	3.1
Tunis	Urban, hilly	4.4	6.0
Le Kef 1	Dry, flat	3.9	5.7
Le Kef 2	Dry, flat	4.0	7.8
Sfax	Dry, very flat, salt lake	4.0	7.9
Mlawa	Forest, agriculture, flat	8.4	5.1
Mostar	Agriculture, hilly	4.5	7.0
Trebinje	Agriculture, hilly	5.6	4.1

It should be noted that the accuracy assessment with GPS transects is only representative for certain areas and does not reflect the slope-dependent and land cover-dependent accuracy of the DSM. Further area-wide accuracy tests will therefore be carried out in the near future.

4. CONCLUSIONS

The results of the accuracy assessment of 18 well-distributed test sites show, that the initially declared and expected DSM accuracy of approximately 10 m for both LE90 and CE90 can be reached without difficulty. In many of the areas, the values achieved are considerably better than the expected values.

Area-wide DSM-processing is currently being carried out for a test area in Northern Italy. A systematic accuracy assessment focusing on slope-dependent and land cover-dependent accuracies will be carried out at this test site. It is expected, that the lateral accuracy of the mosaiced DSM will be improved significantly by triangulating the single DSMs in large blocks containing several hundred scenes.

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